Engineering Analysis

The conclusion reached in the Condition Assessment for the Going-to-the-Sun Road states that a majority of the Road is in need of extensive rehabilitation in order to be responsive to the issues of public safety, environmental concerns, preservation of historic features and natural resources, socioeconomic impacts, transportation needs, and overall visitor experience. Our findings support previous analyses of the Road that also recommend expediting rehabilitation efforts in order to ensure the integrity of this National Historic Landmark for future generations.

Time is of the essence. Current conditions dictate that critical repairs are needed now and the rate of road deterioration is increasing. A comprehensive program is needed to address the critical areas -- an overall plan for rehabilitation, and a long-term maintenance program. This study forms the basis for the development of a comprehensive program.

This engineering analysis starts with the definition of the conditions and conceptual recommendations for rehabilitation of segments of the Road.

The General Management Plan states that rehabilitation is needed to "reconstruct the Going-to-the-Sun Road to preserve its historic character and significance, complete the needed repairs before the road could fail, minimize impacts on natural resources, visitors, and the local economy, and minimize the reconstruction costs." To meet this objective, the Going-to-the-Sun Road will require significantly more funding than is provided under the current repair, rehabilitation, and maintenance programs.

The criteria for the rehabilitation alternatives are developed and carried through the alternative development in *Chapter 3: Development of Rehabilitation Alternatives*.

Alternative development starts with defining the engineering alternatives for drainage, slope stability, retaining walls, guardwalls, and roadway pavement. These engineering alternatives consider cost; schedule; constructibility; techniques; materials; traffic control management; operations; maintenance; historic, cultural, and environmental elements; preservation of natural resources; and visitor management.

Rehabilitation alternatives are presented based on the most prudent engineering alternatives. The most critical criterion to consider in the rehabilitation alternatives is traffic management, as it is directly related to the overall construction cost and completion time, which in turn directly affect the overall social, economic, and visitor impact. Costs and construction schedules are developed for each of the rehabilitation alternatives for evaluation and comparison.

Figure 31:
Tumbling waters pass under Going-to-the-Sun Road as it makes it way to Triple Arches. One of the trademark structures that supports the Road, Triple Arches is in dire need of rehabilitation.

The definitions of the conditions and conceptual recommendations for rehabilitation of segments of the Road are in five sections:

Lake McDonald Section	MP 0.0 to 16.2
West Tunnel Section	MP 16.2 to 23.4
Alpine Section	MP 23.4 to 34.3
Baring Creek Section	MP 34.3 to 43.2
St. Mary Section	MP 43.2 to 49.7

The conditions and prudent engineering recommendations for all work on the Road, except for that specified in the FHWA Retaining Wall Inventory, are included by road segment on the following pages. Following the road segment summary, *Chapter 3: Development of Rehabilitation Alternatives* provides additional detail on the engineering recommendations by topic, including discussion of their specific application to the Road is included. Appendix A includes maps and details of spreadsheets of the deficiencies and the engineering recommendations. Appendix B details the cost estimating of the engineering recommendations and Appendix C provides base information

Lake McDonald Section

MP 0.0 to MP 16.2

Location and Topography: This section, 16.2 miles in length, extends from the bridge over the Middle Fork Flathead River at West Glacier, then northeast past Apgar Campground and Lake McDonald Lodge to its terminus at Avalanche Creek. The topography is flat to moderately inclined, up to two percent. The roadway pavement in this section is approximately 22 to 24 feet in width with varying shoulders of four feet paved to two feet untreated. The pavement and shoulders are overall in fair to good condition. Roadway slumps occur at MP 6.4 and MP 9.4.

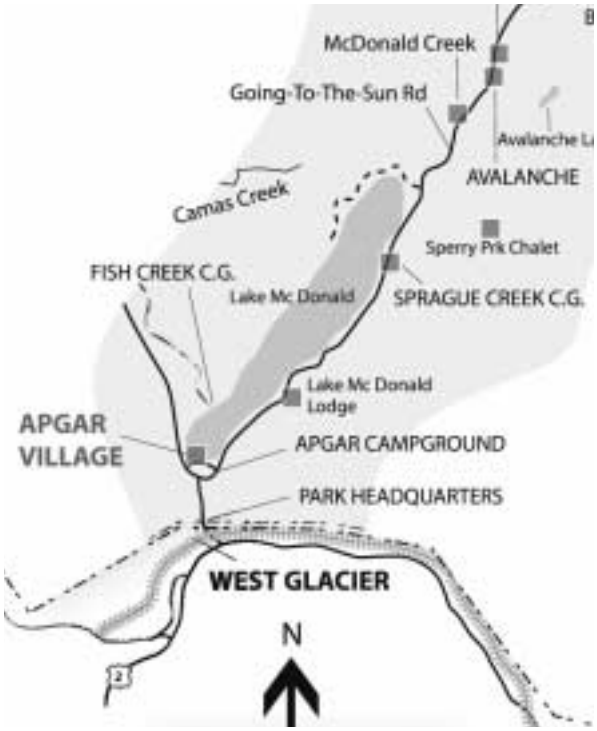

Figure 32: Lake McDonald Section

General Description: This section was recently reconstructed and, with a few notable exceptions, is considered to be in relatively good condition. These exceptions include certain drainage structures and ditches that are damaged or partially blocked with rock and debris, as well as minor bank erosion, earth slumping, and surface deterioration problems that were noted within the roadway cross-section adjacent to Lake McDonald.

Drainage: The overall condition of the drainage in this section is fair. Rock and debris continue to cause problems at stream crossings. Saturated roadway and the adjacent area at MP 9.4 have caused roadway subsidence and pavement cracking. Drainage ditches and structures (including culverts) should be cleaned and repaired as necessary.

Slope Stability: Two areas of roadway slumps are noted in this section, at MP 6.4 and MP 9.4. At MP 6.4, lake erosion is occurring at the toe of a previously constructed

tie-back retaining wall. At MP 9.4 a fairly large slide is active and monitoring of the roadway pavement and foundation should be re-established.

Retaining Walls: Retaining walls in this section are generally good with some mortar repointing, minor structural repairs and maintenance required. A detailed inventory and investigation was conducted by the FHWA and reported in the Glacier National Park Retaining Wall Management System.

Guardwalls: Stone masonry guardwalls in this section are in fair to good condition with some mortar repointing and maintenance needed.

Roadway Pavement: The roadway in this section is fair to good, except for the slide failure at MP 9.4 as noted above. Curvature is gradual and generally follows the shoreline of Lake McDonald. The grade ranges from flat to a gradual incline of about two percent. Continued maintenance is necessary to retain the serviceability of this section. The roadway is starting to show signs of asphalt oxidation and cracking which will require an asphalt overlay or chip seal within the next five years. The roadway foundation is eroding at various locations next to Lake McDonald (wave action). Rip rap or other protective measures should be installed in order to curtail this erosion and protect the facility. There is no curve widening in this area; some curve widening should be made to ensure tire tracking on the roadway surface.

Lake McDonald Section Roadway Segments and Major Features

Landslide Segment: MP 6.3 to 9.1. Lake erosion is occurring at the toe of the slope of the previously repaired slump failure (FHWA Wall 05.90). In order to retard further erosion, erosion protection should be applied at the toe of the repaired slope at lake level, such as placement of large rip-rap at the lake level and rows of erosion logs.

Figure 33: Lake erosion at the toe of the slope, MP 6.4

Figure 34: An active slide at MP 9.4

A fairly large active slide has been previously investigated and monitored by the FHWA in the vicinity of MP 9.1. This slow-moving slide is estimated at 60 feet deep by 600 feet long by 500 feet wide as it affects the Road. There is a noticeable subsidence of the pavement in this area. The FHWA has identified this site as a significant deficiency; however, the roadway does not appear to be in imminent danger of sudden failure, and this slide is not considered a priority at this time. Periodic monitoring of this landslide should be re-established to detect any acceleration of the slide's movement that could cause sudden, major damage to the Road. Mitigation measures may be needed if impacts to the Road section accelerate.

Snyder Creek Stream Crossing: MP 10.8. A concrete slab, 30 feet wide with stone masonry parapets of 37 feet in length, this bridge is in fair to good condition; rock and debris deposits are a continuing source of maintenance problems and regular cleaning is recommended.

West Tunnel Section

MP 16.2 to MP 23.4

Location and Topography: This section of seven miles, extends east from MP 16.2 at Avalanche Creek; then continues past Logan Creek and Packer's Roost to the West Tunnel at MP 23.4. The topography is moderately inclined to fairly rugged. The roadway surface is bituminous pavement, 22 feet wide with two-foot-wide shoulders that range from paved to untreated. It is in generally fair to poor condition.

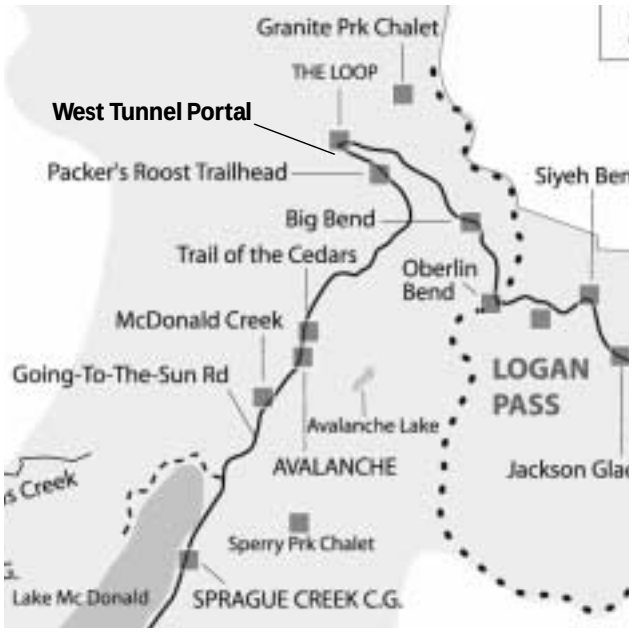

Figure 35: West Tunnel Section

General Description: The western portions of this section are subject to flooding and debris flows. The drainage facilities are worn excessively and in many cases are partially plugged with debris and are therefore only partially effective. The pavement surface is oxidized and cracked, and most of the stone retaining walls and guardwalls are in poor condition due to mortar deterioration and rock displacement. A short section (approximately one mile in length) was reconstructed in 1965 with eleven-foot lanes and three-foot paved shoulders. The pavement sufficiency of this section is, however, similar to the adjacent sections of roadway at the current time. Overall serviceability and sufficiency of this section is rated as fair to poor.

Drainage: Most of the drainage facilities were partially plugged with debris and in poor hydraulic condition. The bottom slabs of the concrete box culverts were cracked and broken with reinforcing bars exposed and significant erosion evident in many cases. The overall drainage condition is rated as poor. This entire section is in need of drainage facility repairs or modifications to protect the existing roadway and historic features. Drainage facilities should be upgraded as appropriate to accommodate normal and high water flow conditions. The concrete slab bottom sections of the box culverts should be replaced or lined with erosion resistance material to retard water intrusion into the box culvert foundation.

Slope Stability: Some portions of the roadway are subject to shallow creep of the colluvium/fill foundation materials. Reconstruction of the outboard edge of the road is needed in some locations to prevent further deterioration and to repair damage from slope creep. Some soil slopes above the road are in need of stabilization in this section.

Retaining Walls: Eleven retaining walls are located in this section ranging from seven to 25 feet in height and 32 to 446 feet in length. Their condition is generally fair to good, with the notable exception of the wall at MP 22.8 which has failed. Most all of the walls are in need of mortar repair or repointing. The failed rock masonry retaining wall at MP 22.8 should be reconstructed since the roadway foundation is in jeopardy at this location. Detailed inventory and investigation is conducted by the FHWA and reported in the Glacier National Park Retaining Wall Management System.

Guardwalls: Stone masonry guardwalls in this section are in fair to good condition with the exception of minor to moderate mortar deterioration.

Roadway Pavement: The roadway in this section is fair to poor. Entering the higher altitudes, curvature becomes more pronounced as the roadway grade increases to approximately six percent through this section. The existing roadway is narrow (eleven foot traffic lanes with minimal or no shoulders) and curvilinear. The approach section to the West Tunnel entrance was recently reconstructed (late 1990s) and is in good condition. The remaining length of this section is, however, considered to be in poor condition and in need of an overlay or reconstruction. Selective curve widening is recommended as a safety consideration.

West Tunnel Section Roadway Segments & Major Features

- ***Avalanche Creek Stream Crossing: MP 16.4.*** This three-span concrete slab is 58 feet long and 27 feet wide, with four-foot sidewalks on each side and stone masonry parapets. It is in good condition.

- ***Red Rock Point Segment: MP 17.4 to 18.4*** The dry stack wall at MP 17.45 is experiencing erosion problems and needs rip-rap placed in void areas and grouted. Near MP 17.95, approximately 200 feet of slump has occurred, with riverbank erosion the likely cause. Some rip-rap and vegetation has been placed, however, additional rip-rap and vegetation is required. Near MP 18.3, the corrugated metal pipe culvert has erosion of the headwall and should be rebuilt.

- ***North Cannon Creek: MP 19.8.*** This concrete box culvert with stone parapets at each end is 22 feet long by 12 feet wide and is in fair to poor due to stream bed load and bottom slab damage. The roadway approach is settling, likely due to saturation, and should be reconstructed by excavating the foundation material within the roadway and replacing it with a combination of geotextile fabrics, washed rock, and structural subgrade.

- ***Logan Creek Stream Crossing: MP 20.9.*** This two-span concrete arch with stone masonry facing bridge is 43 feet long by 22 feet wide (across the Road). Its general condition is fair; however, it is narrow and appears to have inadequate hydraulic capacity for peak flows. The streambed rock and debris load is very heavy during high water conditions and is a continuing source of maintenance problems as illustrated in Figures 36 and 37. Dredging of the streambed is recommended and riprap should be placed to reduce the scour that is occurring along the footer. A cofferdam will be necessary to move the flow to one culvert while cleaning the other. Dredged material could be sorted and used for fill in other locations.

Figure 36: Logan Creek Bridge

Figure 37: Rock and debris nearly fill the bed of Logan Creek

Figure 38: Abrasion on the bottom slab of Haystack Creek stream crossing

Figure 39: Debris accumulation along Haystack Creek

Figure 40: Double box culvert, Alder Creek Stream Crossing

- ***Haystack Creek Stream Crossing: MP 21.5.*** This stone arch culvert with concrete bottom slab is an approximately four by six foot concrete box culvert 24 feet long. The arch support is in fair condition; however, the bottom slab has been badly eroded and is in very poor condition. Reinforcing steel bar is exposed and there are numerous cracks and broken areas in the concrete, as illustrated in Figure 38. The crossing is undersized for the flows and high bed loading is evident. Dredging is recommended and the material could be sorted and used for fill in other locations. An additional concrete box culvert could be added to this crossing to address the flow constraints.
- ***Packer's Roost: MP 22.4.*** The westbound angle of entrance into Packer's Roost is very sharp and sight distances are limited for turning traffic. If this area experiences more use, this intersection should be improved to accommodate turning traffic in a safe manner.
- ***Alder Creek Stream Crossing: MP 22.6.*** This double concrete box culvert with stone parapets has one ten by eight foot barrel and one six by four foot barrel, each approximately 22 feet long. Both culverts are in fair condition except for moderate to minor erosion of the bottom slabs. Grout loss is evident and separation of the headwall and bottom show signs of scour. The stream bed load of rock and debris limits the capacity of these structures during high water conditions and should be dredged. Repair to the headwall and wingwalls is recommended along with abrasion plating of the bottom slab and placing rip-rap at the outlet.

- ***West Tunnel Approach Segment: MP 23.0 to 23.3.*** Roadway drainage in the vicinity of MP 23 is deteriorating. Approximately 150 feet of walls and a concrete pan with drop inlet are recommended to curtail the drainage. The concrete retaining wall with removable railing near MP 23.1 is not crash-tested and not historical. One alternative is to cut the concrete wall at road level, build a core wall and face with appropriate stone on both sides. Approximately 100 feet of stone retaining wall at MP 23.12 has impact damage, grout deterioration, and settlement and requires template rehabilitation with sub-excavation and mortar point and patchwork. Approximately 70 feet of guardwall is tipping at MP 23.19 and should be removed and replaced on a 4 foot slab with drop inlet. The concrete culvert inlet at MP 23.25 is in disrepair and requires replacement with a weathering steel, close-mesh grate. The road at MP 23.25 is experiencing creep and settlement and should be reconstructed with at least an eight foot slab with anchors keyed with the toe wall.

Figure 41: Roadway drainage below the West Tunnel

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Alpine Section

MP 23.3 to MP 34.3

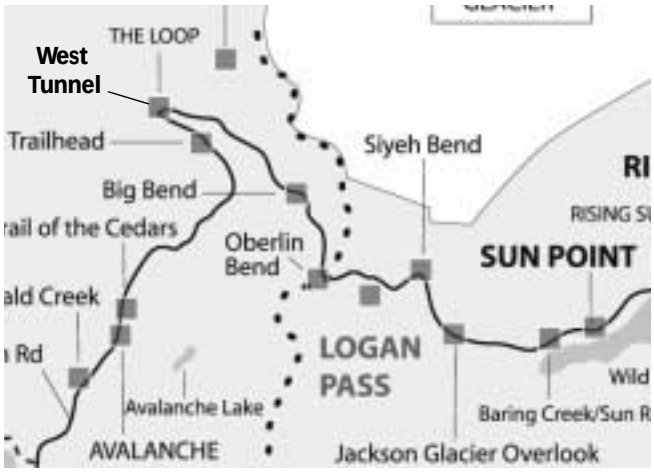

Figure 42: Alpine Section

Location: This eleven-mile section, which is considered to be the most critical part of the Road, extends from the West Tunnel to the top of Logan Pass, then continues east down to Siyeh Bend. The topography is very steep and rugged throughout. The Road is very curvilinear and fairly steep with a sustained grade of about six percent on the western approach to Logan Pass and approaching minus six percent descending the eastern side of Logan Pass. The asphalt pavement ranges in width from just less than 18 feet to approximately 22 feet throughout most of this section. Certain areas have received a number of overlays over the years, which have combined with avalanche forces and foundation subsidence to render many of the guardwalls ineffective as their height above the Road is less than one foot. The pavement has deteriorated in many locations with longitudinal, transverse, and alligator cracking prevalent. The condition of the pavement is considered poor to very poor. There are no continuous shoulders in this section. The existing inboard shoulders are generally extensions of the paved surface to contour with the base of the rock cut.

General Description: The drainage facilities and roadway surface are rated as poor to very poor throughout most of this section. The stone retaining walls, guardwalls, and archways are in various states of deterioration and collapse due to mortar deterioration, rock displacement, and foundation failure. Rockfall hazards, pavement and shoulder saturation and distress, and side slope instability are significant. Avalanche and rock debris chutes are also evident at many locations throughout this section. The overall rating of this section is considered poor to very poor.

Drainage: Significant drainage work is needed throughout this section. All drainage structures or facilities should be cleaned and repaired. Pavement cracks should be sealed against moisture intrusion, and additional roadway cross drains, drop inlets, valley pans, and other drainage facilities should be installed to accommodate drainage patterns. Plugged or otherwise poorly maintained culverts, ditches, and roadway

cross drains are evident throughout this section. Drainage flow is arrested or interrupted, causing water to accumulate and seep across and into the roadbed, or find alternate drainage routes. The roadway subgrade is saturated and weakened by water intrusion, contributing to slump failures and fill slope distress. Stone guardwalls and retaining walls have shifted and weakened or failed in certain instances. Running or standing water on pavement surfaces creates further safety hazards to the highway user. Clean out, repair, and improvement of plugged and damaged drainage facilities should be undertaken as soon as possible to slow the overall deterioration of the Road. Erosion of slopes below the Road is occurring from drainage from culverts and erosion protection is required in several locations. Localized drainage studies should be conducted to determine the most appropriate drainage investments for long term stability of the Road and its structures.

Slope Stability: Much of this section has rock cuts above the road and fill slopes below, all created during the initial road construction. Several areas within the section require scaling of rock cuts for safety and stabilizing raveling soil slopes. Scaling should proceed judiciously throughout this section and include on-site geotechnical personnel to direct scaling operations on going basis. Safety of the workers in the rehabilitation will require special attention and in a few areas, positive protection will need to be in place for the work on the roadway.

Retaining Walls: There are approximately 93 stone masonry retaining walls within this section beginning at MP 17.2 and extending to MP 33.0 with heights ranging from two to 34 feet, and lengths ranging from 23 to over 300 feet. The general condition of the retaining walls is considered fair to poor, with most estimated to be in fair condition considering their age and location. Practically all of the walls need mortar repointing and miscellaneous repair work. However, five of the walls have failed and will have to be reconstructed using plans developed by FHWA over the next two years. Failed walls are located as follows:

- MP 23.65
- MP 23.47
- MP 23.42
- MP 27.58
- MP 32.95-33.0

All are discussed below and in the detailed inventory and investigation by the FHWA, reported in the Glacier National Park Retaining Wall Management System. These walls must be rebuilt. This rebuilding can reuse the original stones to preserve the

historic character of the walls. The stone masonry arches at MP 24.56 and MP 29.6 should be repaired or reconstructed as soon as feasible. Likewise, certain stone masonry retaining walls that have failed, such as at MP 27.6, should be reconstructed.

Guardwalls: The general condition of the guardwalls in this section is poor to very poor. A significant portion of these walls provides very little or no protection to the public due to lack of height above the road surface, which in some areas is only six inches. Most of the guardwalls are in dire need of repointing. Many sections have been destroyed or are failing due to avalanches, rock fall, snow load, foundation failure, mortar and stone deterioration, and vehicle impact. The guardwalls should be reconstructed or rehabilitated throughout this section.

Roadway Pavement: The roadway pavement through this section ranges from poor to good. Moisture intrusion has weakened the foundation in many instances causing slippage and subsidence. In certain areas the foundation has been recently strengthened by the installation of micro-pile stabilization or tie-back retaining walls. Most of the roadway foundation will need improved drainage and stabilization. A chip seal or emulsified seal should be applied throughout this section as an interim measure to help protect the remaining facility. This area may provide significant roadbase material during rehabilitation if the excavated pavement and subgrade are recycled. Once the roadway foundation and drainage repairs have been made, the entire section should be repaved with new materials.

It is recommended that roadway width, alignment, and other physical features be carefully reviewed with respect to the functional safety and convenience of the traveling public as well as to the historical significance and environmental considerations of this area, as many of the features of the roadway do not meet current roadway standards. Likewise, turnouts or parking areas should be designed and constructed with visitor experience and public safety in mind.

Alpine Section Roadway Segments and Major Features

- ***West Tunnel Segment: MP 23.3 to 24.0.*** Approximately 2000 feet of eroded soil cuts above the road between MP 23.3 and 23.6 need repair to minimize or halt the erosion. These cuts are good candidates for bio-remediation, using a wire mesh biomat. The concrete box trench drain at MP 23.62 shows erosion at its outlet and requires rip-rap. Curb needs to be added at the uphill portal of the tunnel

Figure 43: Missing section of guardwall near MP 24

at the roadside waterfall. At MP 23.68, 20 feet of guardwall is missing and needs reconstruction on a 4 foot slab along with a new trench drain across the road. The retaining wall at MP 23.75 (FHWA Wall 23.44) has broken stones and grout cracking and requires repointing. The retaining wall at MP 23.75 (FHWA Wall 23.47) is moving and grout is failing and needs repair, currently slated for this year. The retaining wall at MP 23.8 (FHWA Wall 23.51) shows some grout cracking and the road is subsiding in this area. Repair of this area requires template rehabilitation as well as mortar repointing. The retaining wall at MP 23.84 (FHWA Wall 23.54) has tilted and moved and requires rehabilitation, currently scheduled for 2004. The rock face above the Road at MP 23.88 has loose rock and requires scaling. Approximately 300 feet of concrete valley pan with outlets are needed at MP 23.9 to address the drainage against the walls. The retaining wall at MP 23.9 (FHWA Wall 23.64) requires rip-rap to control the toe erosion. The retaining wall at MP 23.9 (FHWA Wall 23.64) is failing and should be rebuilt on a concrete footing. The retaining wall at MP 23.98 (FHWA Wall 23.66) shows settlement and erosion at the footing and requires rehabilitation, currently slated for 2004. The rock face above the Road at MP 23.98 has loose rock and requires scaling.

Figure 44: South portal of West Tunnel

Figure 45: North portal of West Tunnel

- ***West Tunnel: MP 23.6.*** The concrete tunnel, which is 205 feet long and 22 feet wide, is generally in good condition. The rock masonry on the west and east portals of the tunnel is crumbling and in disrepair and repair is needed. The concrete lining shows numerous cracks along the entire length of the tunnel which appear to have been healed by natural processes and are not considered a structural problem at this time. The window ports in the tunnel are in fair condition with the exception of some loose rock on the outside of the ports that should either be scaled or bolted. The pavement is in fair condition with few cracks or undulations.

- ***The Loop Segment: MP 24.0 to 24.5.*** The work in this segment includes that work needed outside of the current rehabilitation of the Loop. The asphalt curb at MP 24 is failing and the shoulder is raveling for about 250 feet. The curb should be removed, along with about two feet of the asphalt, and replaced. Located at MP 24.1 are a few hundred cubic yards of rock that could be used for rehabilitation of stonewalls. Recovery of this material can be accomplished with a slusher system. The twin CMP drainage crossing west of the Loop has partially failed. A pavement patch has been placed

to fill the void created by the partial collapse. A new CMP is necessary to correct this deficiency. Approximately 500 feet of guardwall at MP 24.5 has low freeboard and the roadway should be lowered approximately 6 inches to correct this deficiency. The concrete pipe culvert at MP 24.5 is damaged at the outlet and requires replacement.

- ***The Loop: MP 24.2.*** The dry stack wall and drainage at The Loop is currently under rehabilitation and construction techniques, traffic control methods and workmanship were reviewed. The overall design appears adequate with the exception that pedestrians using the Granite Park Trail must cross the road with minimal sight distance, a condition that should be addressed. Drainage in the Loop parking lot requires an outlet to evacuate standing water. Also within the Loop parking lot, some impact damage to guardwall was noted, along with about 200 feet of undermined guardwall, which could be repaired by grouting. Traffic control operations appear to work well. Workmanship, in general is good, however, more attention could be paid to the stone masonry work to achieve a more historically acceptable look on all sides of the walls.

Figure 46: Construction at The Loop, June 2001

Figure 47: Damage to the parking lot guardwall at The Loop

- ***Crystal Point Arch Segment: MP 24.5 to 25.3.*** Guardwalls in this segment have sunk below the required height, and roadway subsidence is evident. The roadway should be lowered at least six inches at MP 24.6 for 100 feet, and at MP 24.8 for150 feet. This can be accomplished using template rehabilitation by subexcavation and material replacement. Approximately 100 feet of concrete slab and pan is cracking and spalling at MP 25 and should be replaced after subexcavation of the roadway template. Drainage in this segment flows against the walls at MP 24.8 and MP 24.9, and additional cross drains, drop inlets, and scuppers should be installed. The CMP headwall at MP 25 (Sta. 927+10) is damaged causing erosion into the Road and should be repaired and a bollard added to regain roadway width. Approximately 300 feet of guardwall is low and is tipping at MP 24.66; 125 feet of stone retaining wall is low and tipping at MP 24.7. These should be rehabilitated and founded on eight-foot slabs (at a minimum). Scuppers are recommended in these walls for drainage of the sheet flow across the road. The veneer is peeling from the concrete on the retaining wall at MP 24.9. The veneer should all be removed and replaced in a more historically patterned fashion. The guardwall portion of the retaining wall at MP 25 (Sta. 929) is damaged and failing and should be replaced. Subsidence of the guardwall at MP 25 (Sta. 927+75) is occurring due to the raveling below the wall. A drystack wall can be built below this guardwall in the raveled area to stop the subsidence. The random rubble guard wall at MP 25 (Sta. 926+30) has subsided due to foundation problems and should be rehabilitated for approximately 125 feet by lowering the roadway template and repairing the foundation.

Figure 48: Poor drainage in the vicinity of MP 25

- ***Crystal Point Arch: MP 24.9.*** This rock masonry archway and CMP drainage feature (Figure 49) is approximately ten feet in width (along roadway) and 24 feet in length (transverse to roadway). This arch provides support for the roadway and

egress for a short section of CMP carrying local drainage across the roadway. The rock wall inside support for this structure has completely collapsed leaving a void approximately three feet deep by six feet wide by eight feet long under the roadway. The inside foundation material has dissipated and the arch foundation on the outside of the roadway has deteriorated significantly. The condition of this structure is considered very poor to critical, as illustrated in Figure 50.

Figure 49: Crystal Point Arch

The entire upstream support of the arch has collapsed (Figure 50) and most of the roof shows fractures and failure stress, causing progressive subsidence of the roadway and pavement section. Continued roadway subsidence will further restrict drainage features, accelerate roadway failure, and detrimentally affect the highway user. Complete failure of this weakened roadway section could occur at any time, which could result in immediate Road closure and potential loss of life and property.

Figure 50: Damage underneath Crystal Point Arch

This site should be monitored carefully by maintenance personnel and all necessary actions should be taken to restore the roadway to a safe and serviceable condition. The FHWA has completed an initial study of the arch and has developed a repair option that appears to be consistent with structural, safety, and historic preservation values. It is recommended that the FHWA

Figure 51: Catch basin damage near MP 25.2

Figure 52: Drainage improvements are needed near MP 25.4

Figure 53: Rock scaling and roadway template adjustment are needed at MP 25

plans and designs, or a similar repair option, be implemented as a priority consideration at this site.

- ***Alder Creek Segment: MP 25.1 to 26.3.*** Drainage improvements in this segment include cleaning and repair of culverts, headwalls and inlet grates at the following locations:

  - MP 25.1(Sta. 922+60)
  - MP 25.2 (Sta. 921+30) (Figure 51)
  - MP 25.4 (Sta. 919+70) (Figure 52)
  - MP 25.6 (Sta. 907)
  - MP 25.8 (Sta. 902+50)
  - MP 26.1

  A new 30-inch reinforced concrete pipe (RCP) should be installed across the roadway at MP 25.5 (Sta. 912+40). Drainage would be improved at MP 25.2 (Sta. 909-910) with the addition of two inlets. Rock faces above the Road that require scaling include areas in the vicinity of MP 25.1 (Figure 53), MP 25.3, MP 25.7 and MP 26.1. The uphill soil cut at MP 25.5 (Figure 54) requires stabilization, preferably with bioremediation. The retaining wall at MP 25.1 shows foundation problems and a minimum eight-foot roadway slab anchored with tie-backs should be constructed along with the rebuilding of the top four feet of wall. The retaining wall at MP 25.5 (Sta. 909) shows undermining of the footing and footing repair and mortar pointing and patching is required. The retaining wall at MP 26 shows grout cracking and spalling of the top 8 to 10 feet and requires point and patch of mortar. The roadway shows movement

and the walls are tipping at MP 25.3 (Sta. 918) and MP 25.3 (Sta. 909) and requires a minimum 8 foot slab, template rehabilitation, and rebuilding of the top 2 feet of the guardwall. For 400 feet at MP 25.2 (Sta. 911-915) slope creep is enhanced by water in the roadway and roadway template rehabilitation is required. At MP 25.5 vertical roadway movement is evident and an eight-foot anchored roadway slab should be installed. Fines are washing out under the roadway at MP 25.6 (Sta. 908) and filling with flow fill should alleviate the problem. The guardwall on retaining wall at MP 25.6 (Sta. 907) is in disrepair and requires rebuilding. The area of MP 25.7 to MP 26.1 (Figure 55) has about 500 feet of combined missing guardwall and tipping guardwall and requires rebuilding on roadway slabs of varying widths 4 to 8 feet with portions anchored. Approximately 100 feet of guardwall in the area of MP 26.1 does not show enough freeboard, and the roadway template should be adjusted to provide adequate height as well as correct the roadway superelevation deficiencies.

Figure 54: A good opportunity for bio-remediation in the vicinity of MP 25.5

Figure 55: Roadway template adjustment is needed to correct guardwall height deficiency near MP 26

Figure 56: Significant rehabilitation work is needed in the vicinity of Haystack Creek

Figure 57: Rock scaling, retaining and guardwall work, and template adjustment are needed near Haystack Creek

- ***Haystack Creek Segment: MP 26.9 to 28.0*.** Significant rehabilitation work is required in this segment (Figure 56). Drainage improvements consist of re-lining or replacement of CMP and installation of scuppers at MP 27; repairing the undermining of the concrete box at MP 27.1; and repair of the existing inlets, or providing new inlets and bollards at MP 27.6, MP 27.7, and MP 27.9. The headwall on the CMP at MP 27.3 (sta. 638) requires replacement. Rip-rap end treatment is needed on the drainage crossing at MP 27.7 (Sta. 646). Scaling of rock faces above the roadway is needed between MP 27 and MP 27.1 and at MP 27.6 (Figure 57). The uphill soil cut at MP 27.8 requires stabilization, preferably using bio-remediation. The retaining wall at MP 27 shows impact damage, and approximately 300 feet is in need of repair. Subsidence is occurring behind the retaining wall at MP 27 (Sta. 626) and roadway template rehabilitation is required. Approximately 400 feet of the retaining walls between MP 27 and MP 27.2 have experienced avalanche damage and the top 4 feet of the walls should be rebuilt. The retaining wall at MP 27.4 (Sta635-635+50) shows subsidence and leaning and will require a roadway slab of at least 12 feet anchored with piles and tie-backs and

reconstruction of the top 4 feet of guardwall. The roadway shows signs of subsidence at the vicinity of MP 26.2, MP 26.9, and MP 27.6 and will require the roadway template to be lowered. Approximately 250 feet of the guardwalls between MP 27.4 and 27.5 are tipping and should be replaced on footings. Approximately 900 feet of removable rail in this segment should be replaced with crash tested rail or avalanche resistant guardwall, with most of it on moment slabs or footings. The 150 feet of missing guardwall at MP 27.3 (Sta. 631) should be replaced. Approximately 150 feet of guardwall at MP 27.3 (Sta. 632+30) shows impact damage and should be removed and replaced.

- ***Haystack Creek Stream Crossing: MP 27.3.*** This concrete box culvert with stone parapets is 23 feet long (transverse to roadway) by ten feet wide (parallel to roadway). This structure is in good condition with the minor exception of needed stone masonry repointing on the parapets. The stonework on the walls does not meet historic standards and the existing rock should be removed and rebuilt to historic standards.

Figure 58: Haystack Creek stream crossing

- ***Big Bend Segment: MP 28.8 to 30.0.*** Drainage in the vicinity of the Weeping Wall (Figure 59) requires improvement. Inlet grates and bollards are needed at MP 28.8 (Sta. 683), MP 28.9 (Sta. 686-691), MP 29.3 (Sta. 697+75), MP 29.6 (Sta. 704+80 and 709), MP 29.7 (Sta. 712+50) and MP 29.8 (Sta. 720-721). Scaling is needed on the rock cuts at MP 29.6 (Sta. 710+50), MP 29.7, and MP 29.9 (Sta. 718+75-723). Rock scaled in this area may be suit-

Figure 59: Weeping Wall

able for rebuilding of stone masonry walls. A wire mesh bio-remediation should be installed at MP 29.9 (Sta. 717) to address the erosion of this uphill soil cut. The retaining wall at MP 29 (Sta. 688) shows grout cracking and mortar pointing and patching is required. The retaining wall at MP 29.7 (Sta. 712+50) (Figure 60) is tipping and the roadway shows movement, and will require a roadway slab of at least 8 feet, anchored with piles and tie-backs, and rebuilding of the top 4 feet of guardwall for about 100 feet. The reinforced concrete tie-back wall at MP 29.9 (Sta. 720-721) has missing stone facia and should be replaced to historic standards. Guardwalls are tipping and subsidence is evident at MP 28.9 (Sta. 685-687), MP 29 (Sta. 688-691), MP 29.4 (Sta. 697+50), MP 29.5 (Sta. 706), MP 29.7 (Sta. 713+50), and MP 29.8 (Sta. 717), all of which will require a minimum of a 4 foot slab or footing for foundation and rebuilding of the walls and some roadway template rehabilitation. At MP 29.1 (Sta. 690+50) the concrete core guardwall has exposed concrete on the back. Either rock facia should be added, or bush hammering and staining of the concrete should be done. The guardwall at MP 29.9 (Sta. 718+25) has incompatible rock facia and should be replaced, or the outside concrete face should be bush hammered and stained. A significant source for masonry rock is material that has been cast over the roadside at MP 29.3 (Sta. 698), which can be recovered using a slusher.

Figure 60: Drainage, retaining wall, and roadway rehabilitation are all needed at MP 29.7

- ***Overhang Hazards: MP 29.*** The rock fragments and overhang hazards next to the roadway in the vicinity of MP 29 pose a threat to park traffic as shown. Sections of vertical rock columns and rock overhangs are precariously perched adjacent to the roadway with significant fractures and separations from the stable rock slope. These fractured areas contain fairly large rock segments (over one ton), which present an imminent rockfall hazard to the roadway user. Rock scaling operations should be undertaken through this area and other similar areas insofar as practical to remove specific hazard rocks and stabilize the rock slope. Due to the extensive potential for rockfall above and adjacent to the Road, it is recognized that specific rock scaling operations will lessen but not eliminate nor mitigate rockfall hazards; however, some limited rock bolting will help reduce the hazards.

- ***Slabs at Weeping Wall, MP 28.1 to 28.8.*** Approximately 1,000 linear feet of concrete slabs were placed near the Weeping Wall (MP 29) to correct subsurface damage from moisture intrusion. These slabs have subsequently suffered differential settlement due to continuing roadway foundation problems. Removal of these slabs and complete roadway foundation and pavement reconstruction may be needed at this site. Drainage improvements will be needed in this area as well.

- ***Triple Arches Segment : MP 30.0 to 31.4.*** Drainage improvements including replacing inlets, adding inlets, adding scuppers, adding bollards, cleaning of culverts, and rip-rap protection at outlets are needed in the following areas:

  - MP 30.1 (Sta. 724)
  - MP 30.3 (Sta. 732)
  - MP 30.4 (Sta. 734)
  - MP 30.5 (Sta. 739+30)
  - MP 30.6, MP 31.1
  - MP 31.2 (Sta. 761 and 765)

  Relocation and upgrading of the pipe at MP 30.85 (Sta. 752+25) and MP 31.2 (Sta. 761) is also necessary. Scaling is needed on the rock cuts at MP 31.3. A wire mesh bioremediation should be installed at MP 30.15 (Sta. 727) to address the erosion of this uphill soil cut. A rockfall hazard exists throughout this segment; however, any scaling in this area would be visually intrusive and perhaps cause additional hazards. Only judicious scaling should be undertaken. It is recommended that during rehabilitation, efforts be made to protect the workmen from

these hazards. Approximately 200 feet of the guardrock area near MP 31.2 shows slope erosion, and stabilization is needed. Retaining walls at MP 30.8 (Sta. 750+75 and 752) are eroding beneath their footings. Rebuilding under the footings, grouting, and mortar pointing and patching is necessary. The retaining wall at MP 31.4 has undermining of the footing and is currently scheduled for rehabilitation. The roadway in this segment is showing signs of subsidence and rehabilitation of the roadway template is required for approximately 500 feet and roadway template rehabilitation is needed. Approximately 3600 feet of guardwalls in this segment are tipping and/or subsiding and need to be replaced, preferably on footings or slabs, with about 2300 feet on roadway slabs with anchors. Approximately 150 feet of the reconstructed guardwall at MP 31 is a different color than its adjacent walls and should either be stained or the rock replaced. Approximately 300 feet of removable rail in this segment should be replaced with crash-tested rail or avalanche resistant guardwall. Approximately 500 feet of guardwall in the area of MP 31.2 is damaged and requires replacement, preferably with avalanche-resistant guardwall, reinforced with anchors.

Figure 61: Significant roadway rehabilitation is needed in the vicinity of Triple Arches

- ***Triple Arches: MP 30.1.*** The triple arch masonry roadway support, approximately 50 feet in length, provides support for the Road over precipitous cliff areas. Its condition is fair to poor. The lower rock cliff support for this structure has failed, necessitating intermediate corrective action (rock bolts, grouting of cracks in the cliff, and steel beam lateral support devices). In addition, to provide a minimum guardwall height in this area, the roadway template should be lowered for the full roadway width. Improvements to this structure have been designed by FHWA and should be implemented as soon as funding is available. The stone masonry of the structure and associated guardwall is in need of repointing and repair.

Figure 62: The roadway above Triple Arches

Figure 63: Rock scaling is needed near MP 31.8

- ***Oberlin Bend Segment: MP 31.8 to 32.6.*** Rock scaling at MP 31.8 and shoulder work is needed for most of this segment (Figure 63). Guardwalls are extensively damaged and need replacement, preferably on footings in this area. Some roadway template work is needed, which can be accommodated with roadway slabs and overall shouldering.

Figure 64: Drainage improvements, rock scaling, and roadway rehabilitation are needed in the vicinity of MP 33

Figure 65: East Tunnel

- ***East Tunnel Segment: MP 32.0 to 33.4.*** Drainage across the road occurs at MP 33.4 (Sta. 830) and should be corrected with an RCP pipe under the roadway and outlet protection. Scaling of the rock cuts above the roadway is needed in the area of MP 33.3. The roadway for about 150 feet is settling and requires template rehabilitation in the vicinity of MP 32.9 (Sta. 818) along with the rebuilding of the guardwall in this area on a new footing. A roadway slab anchored with micropiles and tiebacks appears to be the best solution; however, a geotechnical investigation should be conducted to support the design. Roadway shoulder and rock wall undermining and deterioration east of the East Tunnel, approximately MP 33.3, threatens the roadway cross section. This section of roadway (about 400 feet in length) exhibits continuing and progressive erosion and deterioration. Significant sections of stone guardwall have been damaged and destroyed by this erosive action. Guardwalls at MP 32.2 (Sta. 818), MP 33 (Sta. 822+50), MP 33.2 (Sta. 826), MP 33.3 (Sta. 862), and MP 33.4, all need significant repair including reconstruction on footings or slabs, preferably with an avalanche resistant guardwall in most cases. The masonry walls near MP 33 show grout cracking and some subsidence and should be rehabilitated along with the roadway template rehabilitation in this segment.

- ***East Tunnel: MP 33.2.*** This concrete lined tunnel is 408 feet long by 21.5 feet wide, and is in good condition. The stone masonry guardwall and retaining wall approaches to the tunnel are in need of work as shown in Figure 65.

Baring Creek Section

MP 34.3 to MP 43.0

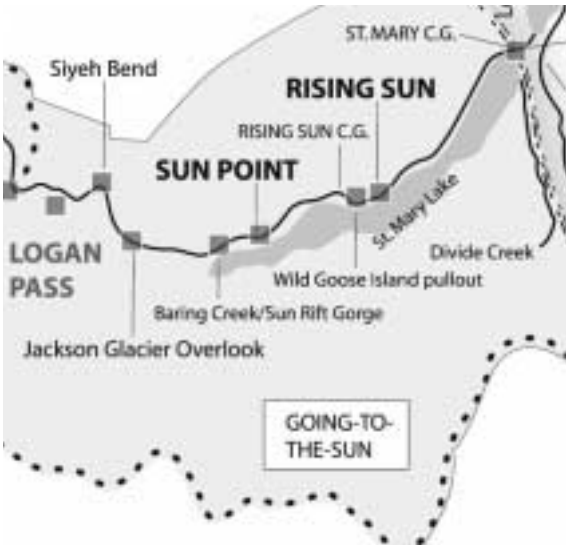

Figure 66: Baring Creek Section

Location and Topography: This nearly nine-mile section from Siyeh Bend extends east past Sunrift Gorge and Baring Creek to the St. Mary Lake access road intersection at Rising Sun. Its topography is considered moderately rugged. The roadway, 22 feet wide of asphalt concrete with variable width shoulders, is in fair to poor condition.

General Description: Rock guardwalls and retaining walls are in various stages of deterioration due to spalling mortar joints and rock displacement. The Baring Creek bridge is in fair to good condition due to recent rehabilitation activities. The pavement surface is moderately cracked and oxidized and shows signs of minor settlement and foundation failure. Occasional portions of the inboard road cut have loose rock hazards or soil slopes raveling from erosion.

Drainage: The overall drainage condition of this section is fair to poor. Existing ditches and culverts are partially plugged and overgrown with vegetation. Possible water intrusion into the roadway foundation was noted at several sites. Debris flows require attention, especially in how they relate to the drainage in this section. The drainage ditches, culverts, and other drainage facilities should be cleaned, reconstructed as necessary, and properly maintained.

Slope Stability: Slopes above the roadway on the east side of Siyeh Bend are raveling due to surface erosion on the steep soil cuts. Other than this and some debris flows, most of this section requires little slope stability remediation.

Retaining Walls: Retaining walls are not a major issue in this section, except at Dead Horse Point where some minor rebuilding is necessary. The stonework on the retaining walls, in general, requires mortar repointing as the four walls in this section are in fair to good condition.

Guardwalls: The guardwalls in this section are in generally fair to poor condition from subsidence, stone displacement, and general deterioration.

Roadway Pavement: The general roadway foundation condition is fair. The curvature is quite modest except for one curve to the left of 110 degrees or more in the vicinity of the Wild Goose Island vista points. The roadway approaches and parking areas for the historic vista points for Wild Goose Island should be redesigned and reconstructed for the safety and appreciation of the visitor, as well as for historic values. An emulsified seal or chip seal should be applied to existing paved surfaces to protect them from moisture intrusion and progressive deterioration. In addition to the above noted activities, this section should ultimately be scarified. The existing pavement material could be recycled into a stabilized base course. A new asphalt concrete pavement should be constructed and the parking areas resurfaced.

Figure 67: Siyeh Bend

Figure 68: A culvert at MP 34.8

Baring Creek Section Roadway Sections and Major Features

- ***Siyeh Bend Segment: MP 34.7 to 35.0.*** Drainage and superelevation deficiencies appear on the roadway in the vicinity of MP 34.8 and removal of 6 inches of asphalt is recommended to adjust the slope. At MP 34.8 the masonry rundown allows water and debris to unim-

peded to the culvert's headwall creating damage (Figure 68). One solution in this situation is to create energy dissipation by using rocks strategically placed in the flow. The area of MP 35 (Figure 69) shows progressive erosion of the steep soil cuts and exposed boulders could tumble onto the roadway. Bioremediation and minor realignment of the roadway would provide for a catch ditch (Figure 70).

Figure 69: Raveling soil slopes at MP 35

- ***Siyeh Creek Stream Crossing: MP 34.8.*** This concrete box culvert, approximately 30 feet long (transverse to roadway) by ten feet wide, is in fair to good condition, receiving high sediment flow. An overlay of reinforced concrete, epoxy, or other abrasion-resistant material is needed to repair the bottom slab throughout its entire length. Rip-rap should be used near the outlet for erosion protection.

Figure 70: Minor roadway realignment would facilitate slope rehabilitation

Figure 71: Debris flow near MP 36.5

Figure 72: Rock scaling and guardwall rehabilitation is needed near Dead Horse Point

- ***Jackson Glacier Segment: MP 36.7 to 37.4 .*** Three debris flows exist at MP 36.1 and MP 36.7. High sediment and erosion is evident at each location. The potential solutions for these include cleaning out of the debris and installation of rock drops, trash guards, and replacement or addition of RCPs under the roadway.

- ***Baring Creek Stream Crossing: MP 39.5.*** This earth-filled reinforced concrete arch with stone masonry facing on its sides and parapets of 68 feet in length is in fair to good condition. The stone masonry parapets need repointing, otherwise the structure is in good condition.

- ***Dead Horse Segment: MP 41.1 to 41.5.*** Within this segment, considerable guardwall work is needed. The guardwall at MP 41.1 is settling and additional wall height is needed. The top 4 feet of retaining wall at MP 41.5 needs to be rebuilt. The adjacent guardwall is low and roadway milling in this area may provide enough wall height. Another portion of this guardwall is moving and subsiding and should be rebuilt on a slab supported with piles. The rock face above the Road in the area of MP 41.1 requires scaling.

Figure 73: Road realignment is recommended for the pedestrian area near MP 43

- ***Wild Goose Segment: MP 42.8 to 43.2.*** The roadway approaches and parking areas for the historic vista points for Wild Goose Island (Figure 73) should be redesigned and reconstructed for the safety and appreciation of the visitor, as well as for historic values. The westbound roadway parking area at the Wild Goose Island vista point MP 43 should be reviewed and either removed or redesigned to accommodate traffic in a safe manner. The current sight distance at this site is very minimal due to the curvilinear alignment of the roadway. This poses a definite safety hazard to vehicles entering or leaving this site and to pedestrians crossing the Road to reach the vista point. It is recommended that the rock outcropping at MP 43 be investigated for possible removal to accommodate a safer roadway alignment through this area. This area is a major visitor attraction due to the vista of St. Mary Lake and Wild Goose Island. The rock generated from this work could be utilized in repair work of the existing rock masonry walls, and the area vacated by the redesigned roadway could be developed into an excellent interpretive vista site with safe and adequate parking for park visitors.

St. Mary Section

MP 43.0 to MP 49.7

Figure 74: St. Mary Section

Location and Topography: This 6.7 mile section extends from the intersection at Rising Sun easterly along the north shoreline of St. Mary Lake to the eastern boundary of Glacier National Park and to the intersection with U.S. Route 89 in the town of St. Mary. The topography is rolling to flat with very little roadway gradient.

General Description: The pavement is generally 22 feet wide with two to four-foot gravel shoulders that are in fair to good condition. This section was reconstructed in the 1990s and is in fair to good condition, except for earth slumping and drainage problems. The drainage facilities are partially plugged, and therefore only partially effective in relieving ground water pressure from the roadway foundation. St. Mary River and Divide Creek floodplains adversely affect the roadway at the east terminus. The overall rating of this section is fair to good.

Drainage. The most significant drainage issue in this section is the Divide Creek Bridge. The Rose Creek and St. Mary Crossings are in good condition. The culvert pipes noted in this section were partially or completely plugged in a number of cases which allows (or forces) the water to seek alternate drainage paths. This has led to saturated subgrade conditions as well as roadway subsidence and premature pavement deterioration. The drainage ditches and structures should be cleaned, repaired as necessary, and restored to proper service. Additional culverts or structures may be warranted to accommodate drainage flow patterns.

Slope Stability. The roadway foundation in this section is fair to good, with the exception of earth slumping in the vicinity of MP 47.7. Lake erosion at the toe of this

slump is actively enlarging the slump area, and recent failures have extended almost to the toe of the existing road fill. Geotechnical investigation should be undertaken to evaluate and monitor the slump area, and immediate action should be taken in the form of erosion protection to the toe.

Retaining Walls. No significant retaining wall issues were noted in this section.

Guardwalls. The guardwalls in this section are generally in fair to good condition.

Roadway Pavement. Most of this section of roadway was reconstructed in the 1990s and is generally in fair to good condition except for minor roadway slumps, back slope raveling, and drainage problems. The roadway pavement in this section is in fair to good condition. Very little curvature exists in the alignment with the exception of the park's eastern boundary. Grades are slight.

St. Mary Section Roadway Segments and Major Features

Figure 75: Roadway and guardwall rehabilitation and rock scaling are needed in the vicinity of MP 43.3

- ***Golden Stairs Segment: MP 43.2 to 43.6.*** The stone masonry retaining wall at MP 43.35 is tipping and the east 75 feet is sagging. Repair consists of providing a slab with core wall as the foundation and rock facia. Guardwall in the vicinity of MP 43.3 is low and additional courses of rock are needed to bring it up to an acceptable height. Scaling is needed in this same area, and rock scaled may be used in the wall rehabilitation efforts. Additional drainage is needed in the vicinity of MP 43.3, and the addition of a three-inlet collection system with one outflow is recommended.

- ***St. Mary Slump Segment MP 47.5 to 47.9*** This slump area has received work in the past yet it continues to slump. Lake erosion at the toe of this slump is actively causing enlargement of the slump area, and recent failures have extended almost to the toe of the existing road fill. Geotechnical investigation should be undertaken to evaluate and monitor the slump area, and immediate action should be taken by providing erosion protection to the toe. It is expected that repairs will be needed to stabilize the slump and specific recommendations can be made following further geotechnical investigation.

Figure 76: High bed loading in Divide Creek

- ***Divide Creek Bridge: MP 49.9.*** This 52-foot long, three-span concrete flat slab box is in fair to good condition, with the exception of its high bed-loading. The stream channel has filled in due to rock and debris deposits. The hydraulic capacity of this structure is inadequate to accommodate high water conditions causing significant deposits of rock and debris in the immediate vicinity of the structure as well as along the adjacent western section of roadway. The roadway traverses through a flood plain from the intersection with U.S. 89 westerly to the western side of the St. Mary River Bridge (approximately ¾ mile). The entire section of this roadway is subject to high water conditions during peak runoff. The three-span structure over Divide Creek is very inadequate to accommodate peak flows and may need to be supplemented by additional openings or structures. A previous study of this area was performed for the park by the FHWA. This area will need considerable study and effort to provide an equitable solution to the problems identified in that study.